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Rare decays of B_c meson

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In present work, we study the rare semileptonic decays of B_c mesons in the framework of covariant confined quark model. Necessary transition form factors are evaluated in the entire dynamical range of momentum transfer. We further compare our results with the different theoretical predictions.

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1. Introduction

B_c meson has served as an ideal candidate to test the standard model of particle physics as it contains both the heavy quarks and mainly decays through weak interactions. Tree level semileptonic decays are very well explored world wide by considering the decay of either c-quark or b-quark. Here, we present our preliminary results on the form factors corresponding the transition $b \to s$ decays and so we will study the rare semileptonic decays $B_c \to D_s^* \ell^+ \ell^-$. For the computation of transition form factors, we have employed the effective field theoretical framework of covariant confined quark model (CCQM) [1–5]. In this model, the hadronic interactions are considered through the constituent quarks only and confinement of quarks are justified with the compositeness condition [6, 7]. The necessary model parameters are quark mass, meson size parameter and universal infra-red cut-off parameter (λ) which removes the divergences appearing in the Feynman diagrams. These parameters are: $m_{u/d} = 0.241$ GeV, $m_s = 0.428$ GeV, $m_c = 1.670$ GeV, $m_b = 5.05$ GeV, $\lambda = 0.181$ GeV and meson size parameters $\Lambda_{B_c} = 2.728$ GeV, $\Lambda_{D_s^*} = 1.556$ GeV.

In general, the transition form factors for the channel $B_c \to D_s^*$ can be expressed as

$$\begin{aligned}
\langle D_s^*(p_2,\epsilon)|\bar{s}\gamma^\mu(1-\gamma^5)b \mid B_c(p_1)\rangle &= \frac{\epsilon_\nu^\dagger}{m_1+m_2}[-g^{\mu\nu}P\cdot q A_0(q^2) + P^\mu P^\nu A_+(q^2) \\
&+ q^\mu P^\nu A_-(q^2) + i\varepsilon^{\mu\nu\alpha\beta}P_\alpha q_\beta V(q^2)]\,, \qquad (1) \\
\langle D_s^*(p_2,\epsilon)|\bar{s}\sigma^{\mu\nu}q_\nu(1+\gamma^5)b \mid B_c(p_1)\rangle &= \epsilon_\nu^\dagger\Big[i\varepsilon^{\mu\nu\alpha\beta}P_\alpha q_\beta T_1(q^2) - (g^{\mu\nu} - q^\mu q^\nu/q^2)P\cdot q T_2(q^2) \\
&+ (P^\mu P^\nu - q^\mu P^\nu P\cdot q/q^2)\Big(T_2(q^2) + \frac{q^2}{m_1^2-m_2^2}T_3(q^2)\Big)\Big].
\end{aligned}$$

Here $P = p_1 + p_2$ and $q = p_1 - p_2$ with p_1 and p_2 to be the momenta of B_c and D_s^{*-} meson respectively. We further compare our results of the form factors at maximum recoil with the other theoretical predictions such as relativistic quark model (RQM) [8], covariant light front quark model (CLFQM), [9] perturbative QCD approach [10] and QCD sum rules (QCDSR) [11]. Note here that in order to compare our results of form factors with literature, we transform our form factors to BSW form factors [12].

Table 1: $B_c \to D_s^*$ transition form factors at maximum recoil along with the comparison with other theoretical approaches

	$V(0)$	$A_0(0)$	$A_1(0)$	$A_2(0)$	$T_{1,2}(0)$	$T_3(0)$
Present	0.283	0.173	0.182	0.190	0.180	0.093
RQM [8]	0.182	0.070	0.089	0.110	0.085	0.051
CLFQM [9]	0.434	0.387	0.274	0.159	0.265	0.231
pQCD [10]	0.33	0.21	0.23	0.25	0.28	0.27
QCDSR [11]	0.54 ± 0.018	0.30 ± 0.017	0.36 ± 0.013	−	0.31 ± 0.017	0.29 ± 0.034

2. Results and Discussion

The Covariant Confined Quark Model allows for a fairly generic analysis of hadronic properties, and this formalism can be used for any number of quarks with any number of loops. In past few

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years, we have been successful in utilising present formalism for the very detailed analysis of different weak observables for charmed [13–19] as well as bottom hadrons [20–24]. In the present work, we have studied the rare weak decays of B_c mesons induced by the $b \to s$ transition at quark level. The form factors corresponding the channel $B_c \to D_s^*$ are computed in the entire q^2 range. In Tab. 1, we compare our results with other theoretical approaches and it is observed that our results of the form factors at the maximum recoil are in good agreement with the perturbative QCD approach [10]. It is interesting to note here that there are significant deviations in the results of form factors at the maximum recoil from various theoretical predictions. However, in the absence of lattice as well as experimental support, it is difficult to comment on the comparative validity of the findings which also includes this investigation.

Using the transition form factors, we also compute the branching fractions of the rare semileptonic decays. The effective Hamiltonian for the $b \to s\ell^+\ell^-$ can be expressed as [25–27]

$$\mathcal{H}_{eff}^{SM} = -\frac{4G_F}{\sqrt{2}}|V_{ts}^* V_{tb}| \left\{ \sum_{i=1}^{10} C_i(\mu) O_i(\mu) + \frac{V_{ub}^* V_{us}}{V_{tb}^* V_{ts}} \sum_{i=1}^{2} C_i(\mu)[O_i(\mu) - O_i^{(u)}(\mu)] \right\}. \tag{2}$$

The C_i's are Wilson coefficients and O_i are the standard model local operators that include the penguin operators, dipole operators and current operators. Using standard transition matrix element and Wilson coefficients along with our computed transition form factors, we determine the rare semileptonic branching fractions using the standard model relations [28]

$$\frac{d\Gamma(B_c \to D_s^* \ell^+\ell^-)}{dq^2} = \frac{G_F^2}{(2\pi)^3} \left(\frac{\alpha |V_{tb}^* V_{ts}|}{2\pi} \right)^2 \frac{|\mathbf{p_2}| q^2 \beta_\ell}{12 m_{B_c}^2} \mathcal{H}_{\text{tot}}. \tag{3}$$

Here, $\mathcal{H}_{\text{tot}}$ is the helicity amplitudes which can be presented in terms of square of helicity form factors via invariant form factors and computed branching fraction comes out to be $\mathcal{B}(B_c^+ \to D_s^{*+}\mu^+\mu^-) = 1.909 \times 10^{-7}$. Further detailed analysis on the branching fractions and other physical observables such as forward backward asymmetry, longitudinal and transverse polarizations and other angular observables are underway. It is worth interesting to note here that many observables for the decay modes corresponding to transition $b \to s\ell^+\ell^-$ have shown deviation from the standard model prediction, the channels considered here can also be tested for the search of new physics at the B factories.

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